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AN INDUSTRIAL HYGIENE EVALUATION OF
F-16 AIRCRAFT REFUELING INSIDE CLOSED
AIRCRAFT SHELTERS

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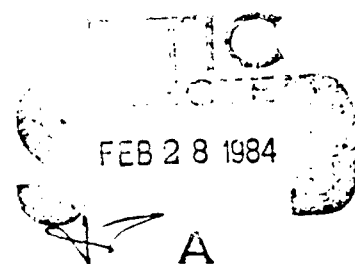
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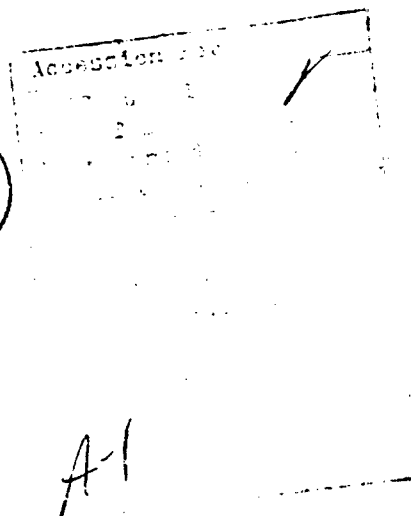
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<p>This study is an industrial hygiene evaluation of F-16 aircraft refueling in closed first generation hardened aircraft shelters; it supplements BEES(W) Technical Reports 81-03 and 81-42. The primary concern is with breathing zone concentrations of fuel vapors displaced from the aircraft fuel tanks during re-fueling. In-shelter F-16 integrated combat turns are also assessed. The major conclusion is that in-shelter F-16 refueling can be performed without limitation. For the case of integrated combat turns, short term exposure limits to carbon monoxide, nitrogen dioxide, and nitric oxide are not exceeded but full workday</p>		

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20 | . . . average carbon monoxide exposure is a potential limitation that requires further study.

PREFACE

This industrial hygiene evaluation was conducted as part of a NATO evaluation of aircraft refueling in closed aircraft shelters. The report presents data and analysis for F-16 aircraft. Since previous reports (i.e. BEES(W) 81-03 and BEES(W) 81-42) discuss background information and survey techniques this report is intentionally brief and focuses on F-16 results and differences between this and earlier work.

The report includes data obtained at Hahn AB, Germany during the week of 7 Mar 83. The study involved many NATO and USAF personnel in addition to our bioenvironmental team. Special gratitude is extended to Mr. Walter Will at HQ USAFE/DEMO for his role in coordinating the entire effort.

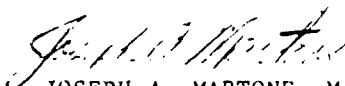
Considerable thanks go to Capt Mark Knuth and Ann Lisa Walrath at Bitburg AB and Capt John Seibert and Sgt Jim Bryson at Hahn AB for contributing independent supporting data to this study.

Individuals from the USAF Regional Medical Center Wiesbaden making significant contributions to this industrial hygiene evaluation and this report are:

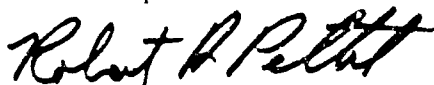
TSgt David J. Hawkins, Technician
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This report has been reviewed by the public affairs officer and is releasable to the National Technical Information Service (NTIS). At NTIS it will be available to the general public, including foreign nationals.

This report has been reviewed and is approved for publication.



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SECTION I

INTRODUCTION

Headquarters USAFE/DFMO requested the USAF Regional Medical Center Wiesbaden to conduct industrial hygiene surveys as part of a NATO evaluation of aircraft refueling inside closed aircraft shelters. Many tests were conducted to cover a wide range of conditions. This report presents the results of F-16 aircraft tests using JP-4 fuel in first generation shelters. Previous work is described in USAF Hospital Wiesbaden Technical Reports BEES(W) 81-03 (Reference 1) and BEES(W) 81-42 (Reference 2). Since procedures and analysis methods for F-16 tests were essentially unchanged from earlier work these factors are only briefly described in this report.

During the tests, representatives from Technischer Überwachungs-Verein (TUV) Rheinland made fuel vapor measurements near the aircraft fuel tank vents to define the explosive hazard region. These results are not included in this report but should be available from HQ USAFE/DEMO, APO NY 09012.

SECTION II

TEST DESCRIPTION

Table 1 summarizes test conditions. All refueling was done with JP-4 (NATO F-40) fuel in a closed unventilated first generation shelter. For each test the aircraft was brought to the shelter after return from a mission to assure realistic aircraft fuel tank conditions (i.e. temperature, volume of fuel remaining, etc.). The amount of fuel transferred, although typical for an F-16, was much less than is common with aircraft such as the F-4, F-15 or F-111 all of which have much larger fuel capacities than the F-16.

On tests A and C the fuel truck was completely inside the shelter. This configuration is possible because F-16 aircraft are smaller than other aircraft. For example, when an F-4 aircraft is refueled (in a first generation shelter) it is not possible to fit the truck inside the shelter and completely close the shelter doors. On test A the fuel truck was a gasoline powered R-5 refueler while on test C an R-9 diesel powered¹ refueler was used. For test B the fuel truck was completely outside the shelter and the fuel line was brought through a slightly ajar personnel door built into the main front ballistic door.

¹ At Hahn AB all diesel powered equipment burns JP-4 fuel. This may not be true at all bases. This report does not address fuel character effects on diesel emissions.

During test C a gasoline powered MJ-1 jammer was operated inside the shelter for about 10 minutes. The jammer was added so the test would simulate in-shelter pollutant emissions during a "cold"¹ integrated combat turn (ICT) in which involves both refueling and weapons loading. The jammer was stationary to avoid interference with TUV measurements. In an actual ICT the jammer would move about the shelter while transferring weapons from storage racks to the aircraft.

The F-16 aircraft is different from other aircraft types considered in previous in-shelter refueling studies (References 1 and 2) because of its relatively small fuel capacity and because it has only a single fuel tank vent. Other aircraft have multiple fuel tank vents; the exact number depending on aircraft type and the chosen configuration of external fuel tanks. The F-16 fuel system vent is under the wing of the aircraft on the same side as the fuel fill point. The fuel fill point is under the wing near the fuselage; the vent port is about midway between the wing tip and the fuselage. The vented fuel vapors are directed downward perpendicular to the shelter floor.

The time required to fill F-16 fuel tanks is about four minutes. The fuel vapor exposure time for crew members was considered as the elapsed time between initiating fuel flow and the time the shelter doors were opened post test. The exposure time was eight to ten minutes (see Table 1).

TABLE 1
F-16 IN-SHELTER REFUELING TEST CONDITIONS

TEST	AMBIENT AIR TEMP. (°C)	FUELING MODE	FUELING TIME (min)	EXPOSURE TIME (min)	VOLUME OF FUEL TRANSFERRED (m ³)
A	13.3	Truck inside shelter	5	8	4.5
B	13.3	Truck outside shelter	4	8	3.8
C	13.3	Truck inside shelter	5	10	4.0

SECTION III

INDUSTRIAL HYGIENE CONSIDERATIONS

On the test in which the fuel truck remained outside the shelter the only pollutant released into the shelter was fuel vapor displaced from the aircraft fuel system. On tests in which the fuel truck or MJ-1 jammer operated inside the shelter, combustion generated pollutants were also released into the shelter environment. Combustion generated pollutants include carbon monoxide (CO), nitric oxide (NO), nitrogen dioxide (NO₂), and unburned or partially burned hydrocarbons. Noise is also a concern when powered equipment is used in a shelter.

¹ A "cold" ICT does not involve aircraft engine operation as does a "hot" ICT.

Considering the short time required for an in-shelter refueling the health criteria which best applies is the short term exposure limit (STEL).

Since the STEL concept is critical for proper interpretation of results, the current STEL definition (Reference 3) is given below:

"A STEL is defined as a 15-minute time-weighted average exposure which should not be exceeded at any time during a work day even if the eight-hour time-weighted average is within the TLV¹. Exposures at the STEL should not be longer than 15 minutes and should not be repeated more than four times per day. There should be at least 60 minutes between successive exposures at the STEL".

In applying the STEL it is important to assure that the workday time weighted average limit (PEL) is also not exceeded.

In earlier reports (References 1 and 2) a different, then current, STEL definition was used to interpret results. An addendum to Reference 2 modified earlier recommendations considering the current STEL definition. This addendum is included as Appendix A.

Table 2 lists the PEL's and STEL's for chemical substances considered in this study. All but the fuel vapor limits come from Reference 3. The listing for fuel vapors is a NIOSH proposed standard for refined petroleum solvents (Reference 4) that is considered by AFMSC/SGPA (Reference 5) as acceptable interim guidance pending publication of official Air Force guidance. The fuel vapor PEL is based on a 10 hour workday while all the other listed PEL's are based on an 8 hour workday.

TABLE 2
HEALTH CRITERIA FOR SELECTED CHEMICAL SUBSTANCES

<u>SUBSTANCE</u>	<u>PEL</u>	<u>STEL</u>
CO	50 ppm	400 ppm
NO	25 ppm	35 ppm
NO ₂	3 ppm	5 ppm
Benzene	30 mg/m ³	75 mg/m ³
Fuel Vapors	350 mg/m ³	1800 mg/m ³

Benzene exposure was considered because benzene is a minor component of JP-4. Previous work (References 2 and 6) indicated benzene exposure is never a problem if the fuel vapor exposure limits are observed.

¹ "TLV" is a registered trademark of the ACGIH, in the context of the STEL definition the "TLV" is equivalent to the PEL.

Noise health criteria are found in AFR 161-35 (Reference 7) and are applied to the case of in-shelter aircraft noise in Reference 8. For hearing protection, the limiting values for total daily exposure listed in Table 5 of AFR 161-35 must be observed.

Having the fuel truck completely inside the shelter (i.e. Tests A and C) along with an MJ-1 jammer (i.e. Test B) meant that emissions from these sources were potentially more significant than in many past studies. In most previous in-shelter refueling or ICT studies either the fuel truck exhaust was emitted outside the shelter or in-shelter plumbing was used for refueling or the shelter doors were open (i.e. during "hot" ICT's) or the work was done in shelters (i.e. modified first or third generation shelters) having a greater interior volume available for dilution of pollutants.

Since this evaluation involved both diesel powered (i.e. R-9 refueler) and gasoline powered (i.e. R-5 refueler and MJ-1 jammer) equipment it is important to generally understand the emissions characteristics of each.

Because diesels operate with much excess combustion air, CO emissions are normally much lower than comparable gasoline powered equipment. Nitrogen oxide emissions from each type of powerplant are the same order of magnitude. Diesels produce particulate matter (i.e. smoke) which at times can be excessive. The organic compounds produced by diesels tend to be more irritating to the eyes and upper respiratory system than organic compounds produced by gasoline powered equipment. The health effects of diesel smoke is the subject of much current research. Preliminary results show the health effects risk to humans to be low (Reference 9).

The eye and respiratory tract irritation is thought to be completely reversible with no lasting health effects (Reference 10). Although this irritation is not a serious health concern, it is nevertheless possible that the irritation may be severe enough to adversely affect job performance. Previous work (References 11 and 12) which has attempted to pinpoint chemical species responsible for eye irritation has shown the measured concentrations of suspected irritants (e.g. aldehydes, acrolein, aromatics) to be an order of magnitude lower than established health criteria for these individual substances. For these reasons, a subjective evaluation of eye irritation was appropriate for this study.

SECTION IV

TEST PROCEDURES AND ANALYTICAL METHODS

Prior to each test, ground crew members were outfitted with personal air sampling equipment designed to measure fuel vapor concentrations in their breathing zones. Only crew members who stayed inside the shelter during a test were outfitted. Two or three crew members were instrumented on each test. As soon as practicable after each test, the personal sampling gear was removed from the crew members. The sampling time was about 15 minutes.

In addition to crew member samples, other samples for fuel vapors were obtained on each test. The sampling equipment was attached to bioenvironmental team members who walked about the shelter during a test. These samples are referred to as area samples.

The method for sampling fuel vapors involved sorption on small (6 mm OD x 70mm) charcoal tubes. This is the procedure recommended by the National Institute for Occupational Safety and Health (NIOSH) for refined petroleum solvents (Reference 4). DuPont Model P-200 personal sampling pumps were used to produce flow at a nominal rate of 0.2 liters per minute through the charcoal tubes. A precision rotameter was used to measure the flow. The exact sample volume at normal temperature and pressure (i.e. 25°C and 760 mmHg) was calculated post test.

Charcoal tube analysis for fuel vapor and, in some cases, benzene was performed at the USAF Regional Medical Center. The technique requires fuel vapor desorption with carbon disulfide and detection by a gas chromatograph equipped with a non-polar column. Distilled JP-4 was used to determine the gas chromatograph calibration factor.

Area CO concentrations were measured with direct reading instruments on tests A and C. On test A a single instrument measured CO at various locations. On test C one instrument was used as in test A but another instrument connected to a strip chart recorder made measurements at a fixed location near the rear of the fuel truck at the side wall of the shelter.

On test C a direct reading instrument measured NO and NO₂ concentrations at the same fixed location used for CO measurements. Area noise measurements were made during test C. Appendix B gives details about these direct reading instruments and calibration techniques.

SECTION V

RESULTS AND DISCUSSION

1. Noise

On test C, with only the R-9 refueler operating, noise levels ranged from 74-78 dBA, and with both the truck and MJ-1 jammer operating, ranged from 91-99 dBA. Using the high values in these ranges to judge the workplace, AFK 161-35 Table 5 would not limit total daily noise exposure (i.e. shelter stay-time) with only the fuel truck operating but would limit total daily noise exposure to 36 minutes if both the truck and jammer were operating as they would during cold ICT's. Because of the short stay-time for unprotected ears, wear of ear plugs or muffs is recommended during cold ICT's.

2. Fuel vapors

Table 3 gives breathing zone concentrations of total fuel vapors. Results are reported in milligrams fuel vapor per cubic meter of air. For a few samples with high total fuel vapor concentration, benzene was also determined. The concentrations shown on Table 3 are calculated as a 15 minute average concentration even though actual exposure times were 8-10 minutes. This approach allows direct comparison of results with the STEL which by definition is a 15 minute average concentration. Table 3 also compares the average total fuel vapor concentration for each test with the average concentration predicted using Figure 1 in Reference 2.

In Table 3 "fueller" refers to the person who performed the connection, monitoring and disconnection of the fuel hose at the aircraft, "fuel truck technician" refers to the person stationed at the fuel truck, and "fireman" to the person holding the fuel line dead man switch near the nose of the aircraft about midway between the other two crew members. "Area" refers to the bioenvironmental engineering team members.

Table 3 shows fuel vapor exposures well below the STEL in all cases and, in many cases, below the PEL. More importantly, predicted average total fuel vapor concentrations are in fairly good agreement with average measured values considering the overall accuracy of NIOSH analytical methods is $\pm 25\%$. This means that recommendations 1-3 of Reference 2 also apply to F-16 aircraft. In practice there would be no limit on F-16 refueling due to fuel vapor exposure since even at elevated ambient temperatures the fuel capacity of an F-16 is less than the recommended maximum fuel transfer volumes shown in Table VI of Reference 2.

Even though the average measured fuel vapor concentrations compared reasonably well with predicted values, it is noteworthy that the predicted values were in each case less than measured values. This probably happened because the F-16 has a single point fuel system vent, and the fueller may stand closer to the vent compared with other aircraft types. Note that in each test the fueller had by far the greatest exposure. The fueller exposure tended to skew the measured average concentration to a value greater than predicted values which were based on refueling aircraft having multiple fuel tank vents. The fueller can reduce his or her exposure simply by not standing so close to the F-16 fuel system vent during refueling. According to Reference 13 current USAFE directives permit the fueller to move after hook up of the fuel line to the aircraft. This did not happen on tests A or C resulting in relatively high but not unhealthful fueller exposures.

Analysis of a JP-4 bulk sample showed it to contain less than 0.7 percent by volume benzene. Breathing zone benzene concentrations (see Table 3) were well below the benzene PEL and STEL. The fuel vapor workday average PEL must also be considered. Appendix A concludes that unless future full day exposure measurements prove differently, there should be no limit on the number of in-shelter refuelings a person could perform since it is very unlikely that the PEL could be exceeded even during wartime exercises.

TABLE 3 SUMMARY OF BREATHING ZONE FUEL VAPOR AND BENZENE MEASUREMENTS

Sample Location	Test	Measured Concentration (mg/m ³)		Predicted Average Total Fuel Vapor Concentration (mg/m ³)	Percent Difference* Total Fuel Vapor Concentration (%)
		Total Fuel Vapor	Benzene		
fueller	A	653			
fuel truck tech.	A	100			
fireman	A	463			
area	A	437			
area	A	247			
Average	A	380		254	+33
fueller	B	380	<1.7		
fireman	B	303	<1.7		
area	B	37			
area	B	113			
area	B	263			
Average	B	219		215	+1.8
fueller	C	593	<1.7		
fuel truck tech.	C	193			
fireman	C	190			
jammer driver	C	160			
Average	C	284		226	+20

$\frac{\text{*measured-predicted}}{\text{measured}} \times 100$

Recently the bioenvironmental engineer at Bitburg AB made full day breathing zone fuel vapor measurements for three fuel crew members designated here as worker A, B, and C (Reference 15). On the day their exposure was measured, worker A pumped 106 m³ of JP-4 during 14 F-15 refuelings, ten of which were in-shelter. Worker B was on a crew which pumped 25 m³ of JP-4 during five F-15 refuelings, three of which were in-shelter. Worker C stayed in the fuel storage area all day. Worker A's day was described as an average workload and worker B's day as a light workload. The ten hour time weighted average exposures were: worker A, 3.9 mg/m³, worker B, 1.8 mg/m³, and worker C, 3.8 mg/m³. All of these exposures are two orders of magnitude below the JP-4 PEL.

The workers mentioned above could not detail shelter conditions (i.e. fuel truck inside or out, shelter doors open or closed) or remember on which refueling they worked inside the shelter. Thus, these results are probably not a worst case. Nevertheless the exposures are low enough to support the argument that the number of in-shelter refueling per day need not be limited because of fuel vapor exposure provided that recommendations 1-3 of Reference 2 are observed.

3. Nitrogen oxides

On Test C the 15 minute average NO concentration was 20.8 ppm, no NO₂ was detected. Although the NO level was considerably higher than levels predicted using diesel vehicle emission factors (Reference 1), it is still 40 percent below the NO STEL and slightly below the PEL, meaning that workday average NO exposure would most certainly be well below the NO PEL. In-shelter refueling should not be limited because of fuel truck NO/NO₂ emissions. It should be noted that jammer operations on Test C also produced NO and this accounts for some of the difference between measured levels and levels predicted using only fuel truck emission factors.

4. Eye irritation

As expected, more smoke and irritation was noted with the diesel powered refueler (Test C) than the gasoline powered refueler (Test A). However, it was not considered severe enough to affect worker performance or cause significant discomfort.

5. Carbon monoxide

Since a gasoline powered refueler was used on Test A, it was the most severe test of fuel truck CO emissions. The in-shelter 15 minute average CO concentration was 80 ppm, well below the CO STEL but somewhat above the PEL. This means a person should be limited to less than approximately 20 closed door refueling in a day to avoid exceeding the CO PEL¹. Since it is unlikely that an individual would even approach this limit, restriction on in-shelter refueling due to fuel truck CO emissions is not needed.

¹ Calculation assumes a 15 minute exposure during a ICT.

On test C it is believed that most CO was due to jammer operations rather than the R-9 refueler since diesel vehicles produce relatively low CO emissions. Reference 14, for example, showed a diesel vehicle produced only 5 percent of the CO emissions of a comparable gasoline powered vehicle. The measured 15 minute average CO concentration was 150 ppm. This is well below the CO STEL but three times above the CO PEL. To prevent a CO exposure above the PEL a person should be limited to approximately 10 cold ICT's in a day¹. It is easy to envision a more severe example. Suppose an ICT used a gasoline powered R-5 refueler and an MJ-1 jammer. Assuming the CO contributions of each were additive the average CO concentration might be 230 ppm, still below the CO STEL but to avoid exceeding the CO PEL a person would be limited to seven ICT's in a day¹. Since a limit of seven ICT's is low enough to have practical significance it is suggested that the assumptions used for its derivation be verified with field testing before any formal limit is imposed on USAFE operations. Future work should include measurement of workday CO exposure during worst case conditions such as during exercises.

Reference 11 showed that CO concentration due to MJ-1 jammer operation in a closed first generation shelter should increase at a rate of 75 ppm per minute. This rate of increase was noted on Test C but only for the first minute or two after CO levels began to increase. Carbon monoxide concentration quickly leveled off to an average of about 150 ppm. Reference 11 therefore would predict much greater CO concentration than measured on Test C.

To assure the measurements were representative, the bioenvironmental engineer at Hahn was asked to repeat CO measurements with an MJ-1 jammer in a first generation shelter. Additional tests were performed with a gasoline powered MJ-1A and a diesel powered MJ-1B jammer.

Each jammer was used to simulate weapons loading during an F-16 ICT with shelter doors open and closed. Jammer run time averaged 11.5 minutes. For the MJ-1A, CO averaged 54 ppm in an open shelter and 88 ppm with shelter doors closed. For the MJ-1B, CO averaged 4.3 ppm with shelter doors open and 23 ppm with shelter doors closed. As expected, the diesel equipment produced much lower CO levels compared to the gasoline powered equipment. The MJ-1A results (i.e. 88 ppm average) were the same order as the EHL measurements (i.e. 150 ppm average). The repeated test results were lower because the MJ-1 probably produces less CO under load than at stationary idle as in Test C.

SECTION VI
CONCLUSIONS AND RECOMMENDATIONS

1. Based on industrial hygiene considerations, F-16 aircraft refueling can be performed in closed hardened aircraft shelters without limitation.
2. The crew member that connects and disconnects the fuel nozzle at the aircraft can reduce his or her fuel vapor exposure substantially by moving away from the fuel tank vent during refueling. This should be encouraged if permitted by USAFE maintenance directives.
3. Ear plugs or ear muffs should be worn during cold in-shelter integrated combat turns.
4. Considering short term worker exposure to fuel vapors and combustion generated pollutants, cold F-16 integrated combat turns in closed first generation shelters is not a health problem. Full workday exposure to carbon monoxide is a potential limitation that requires further study.

These findings do not eliminate the need for workplace industrial hygiene good practice and periodic monitoring at the local level. This report should serve as useful guidance for USAFE medical treatment facility personnel when planning and performing industrial hygiene surveys of in-shelter refueling and integrated combat turns.

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APPENDIX A
ADDENDUM TO TECHNICAL REPORT BEES(W) 81-42

Addendum to Technical Report BEES(W) 81-42
"An Industrial Hygiene Evaluation of Aircraft
Refueling Inside Closed Aircraft Shelters at
Elevated Ambient Temperatures"

AFOSH Standard 161-8¹ requires use of the most recent ACGIH² Threshold Limit Value(TLV) publication for evaluating occupational exposures to chemical substances in Air Force workplaces. The ACGIH updates their TLV publication annually. When TR BEES(W) 81-42 was written the short term exposure limit(STEL) definition found in the 1981 ACGIH TLV publication (Reference 1) was used to interpret workplace fuel vapor exposures. The current (i.e. 1982) ACGIH TLV publication (Reference 2) has an STEL definition significantly different from the 1981 version. Thus it is necessary to re-evaluate the recommendations of BEES(W) 81-42 considering the current STEL definition.

Recommendation number 4 (see pg 17) of BEES(W) 81-42 requires reconsideration because of the STEL definition change. The recommended maximum of four in-shelter refuelings per day per individual was based on the 1981 STEL definition which limited short term exposures to four "excursions" a day with at least 60 minutes between exposures. The problem with the 1981 STEL definition is that the term "excursion" was not defined. Each in-shelter refueling was considered an excursion period hence the recommended limit of four per day per individual.

The 1982 STEL definition eliminates the term "excursion" and instead says that short term exposures "at the STEL should not be repeated more than four times per day." Recommendations 1-3 of BEES(W) 81-42 effectively preclude "exposures at the STEL" during in-shelter refuelings since these recommendations were developed assuming that it was always desirable to keep in-shelter refueling exposures below 50 percent of the STEL. Therefore the four times a day limit contained in the current STEL definition does not have a bearing on in-shelter refueling assuming that recommendations 1-3 are observed.

The STEL definition also requires that the daily time weighted average PEL is not exceeded. To determine whether or not this condition is met would require full workday measurements of an individual's fuel vapor exposure on a day when he or she participated in many in-shelter refuelings. This would be a worst case test. All EHL measurements to date were during a single in-shelter refueling rather than a person's entire workday. With a few assumptions it is possible to estimate the number of in-shelter refuelings a person could perform in a day without exceeding the daily PEL for fuel vapors.

¹ AFOSH standard 161-8 does not apply if a substance specific AFOSH standard has been published (e.g. asbestos, benzene, hydrazine etc.)

² American Conference of Governmental Industrial Hygienists

The PEL for jet fuel is 350 mg/m^3 for a 10 hour time weighted exposure (see TR BEES(W) 81-42 for discussion of this PEL). Thus the permissible daily exposure is:

$$350 \frac{\text{mg}}{\text{m}^3} \times 10 \text{ hr} \times 60 \frac{\text{min}}{\text{hr}} = 210,000 \frac{\text{mg-min}}{\text{m}^3}$$

During an in-shelter refueling assume that an individual experiences a fuel vapor concentration of $900 \frac{\text{mg}}{\text{m}^3}$ (i.e. 50 percent of the STEL) for 30

minutes (This is a worst case assumption if recommendations 1-3 of TR BEES (W) 81-42 are observed). The exposure would be:

$$900 \frac{\text{mg}}{\text{m}^3} \times 30 \text{ min} = 27,000 \frac{\text{mg-min}}{\text{m}^3}$$

To keep within the PEL an individual should not perform more than:

$$\frac{210,000}{27,000} = 8 \text{ in-shelter refuelings in a day.}$$

Because the limit of 8 refuelings is a conservative estimate and because an individual would only rarely exceed this number, there should be no regulatory limit on the number of refuelings a person could perform in one day. If future field measurements of a refueler's whole day fuel vapor exposure contradict this recommendation then limits on the number of refuelings per day or a limit on a person's daily total time in-shelter during refueling should be reconsidered.

This analysis considers fuel vapor exposure during in-shelter aircraft refueling. When refueling is accomplished with a pantograph or with the fuel truck located outside the shelter fuel truck exhaust is not emitted in the shelter and therefore fuel vapors are rightfully the only concern. When refueling occurs with fuel truck exhaust emitted inside the shelter or when other AGE equipment is used during the time the shelter is closed then the combustion generated pollutants from these sources must be considered in judging the workplace environment. An upcoming EHL technical report on an F-16 in-shelter refueling study at Hahn AB will discuss combustion generated pollutants in more detail.

References

- A1. "Threshold Limit Values for Chemical Substances and Physical Agents in the Workroom Environment with Intended Changes for 1981" American Conference of Governmental Industrial Hygienists, 1981.
- A2. "Threshold Limit Values for Chemical Substances and Physical Agents in the Workroom Environment with Intended Changes for 1982", American Conference of Governmental Industrial Hygienists, 1982.

APPENDIX B
DIRECT READING INSTRUMENT DESCRIPTION

1. NOISE

Area noise was measured with a General Radio Model 1565A sound level meter. The 1565A was calibrated on-site using a General Radio Model 1562A sound level calibrator.

2. CARBON MONOXIDE

Area carbon monoxide (CO) levels were measured with Ecolyzer 6000 and 2000 real-time analyzers. These instruments use an electrochemical sensor to measure CO in two ranges: 0-100 ppm and 0-500 ppm. The instruments were calibrated with factory supplied 50 ppm CO calibration gas at frequent intervals during the test periods.

3. NITROGEN OXIDES

Area nitric oxide (NO) and nitrogen dioxide (NO₂) levels were measured with an Ecolyzer Model 7000 real-time analyzer. The Ecolyzer is a portable precision instrument that uses electrochemical sensors to give direct read out of NO in two ranges: 0-10 ppm and 0-50 ppm and NO₂ in two ranges: 0-2ppm and 0-10 ppm. Factory supplied 26 ppm NO calibration gas was used for on-site NO₂ calibration; NO calibration was performed in the laboratory prior to field use of the instrument. After the field testing it was noted that the factory stamped expiration date on the NO calibration gas had past. Subsequent testing in the laboratory showed the calibration gas to actually be 16 ppm, this meant that indicated field measurements were about 1.6 times higher than the true NO concentration. This correction factor was taken into account in calculating the average NO concentration listed in Section V of this report.

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